
57 Computer Control in Mining and Extractive Metallurgy

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Computer control in mining and mineral processing has been weighted heavily to the processing side of the business for the last 50 years. These systems are mature with sensors and actuators that support control rooms for running a variety of process plants from centralized control rooms. Each new plant is designed in today's world to have these capabilities. In fact, these systems have evolved from being operated with large mainframe-type computers to today's PCs. Mining, on the other hand, has been slow to adopt these modern technologies mainly due to the lack of systems capable of supporting large-scale mining operations. For example, a backbone telecommunications system in a process plant has the walls defined boundaries. Mining, on the other hand, is a process whereby the infrastructure is continuously growing. Therefore, bringing the required infrastructure into a continuously growing environment has proven difficult and costly. This trend is changing mainly through the introduction of automation and robotic systems that support basic process control such as the water systems and robotic control of mobile equipment. This chapter looks at the history of computer control systems in mining and mineral processing, describes current trends, and discusses future trends.

INTRODUCTION

Mining is the act of extracting mineral determined to be ore from the earth to be processed in a mineral processing operation. All mining operations have at least some limited mineral processing available on site. Usually, the sophistication of the complex is determined by the unit process operations to make the product or distribution and transportation costs. The mineral extraction process can occur using many potential mining methods. Some of the methods include open pit, caving, bulk stopping and/or selective mining techniques such as cut and fill, as well as room and pillar [1]. Each method and suite of mining equipment has the aim of extracting the mineral at a profit for processing.

The aim of a mineral processing operation is to concentrate a raw ore for subsequent upgrading in processing. Usually, the valuable minerals are first liberated from the ore by comminuting and size separation processes (crushing, grinding, and size classification), and then separated from the gangue using processes capable of selecting the particles

according to their physical or chemical properties [2], such as surface hydrophobicity, specific gravity, magnetic susceptibility, and color (flotation, magnetic or gravimetric separation, sorting, etc.).

Process automation has always played a key role in the mineral process industries and is gaining momentum in mining extraction operations as mobile robotics techniques are being applied. The use of advanced technologies, including modeling, simulation, advanced control strategies, smart equipment, fieldbuses, wireless networks, remote maintenance, etc., is widespread in its many sectors. Information-based technologies are responsible for making mineral processing more efficient and reliable and help the industry to adapt to new competitive environments in a safe and environmentally sound manner. One critical step in achieving these objectives is to develop and apply improved control systems across the full range of applications from mining to processing and utilization.

While mineral processing has had extensive use of many advanced technologies, standard mining applications such as pumping, dewatering, hoist control, and power distribution remain the norm with some individual exceptions in ventilations systems and other mine-wide systems. Overall, the complication and scale of mining operations has delayed the wide adoption of advanced technology. Several stand-alone technologies have seen successful implementation in mining and pilot projects; full-scale mine implementations have been attempted with extremely encouraging results. The Intelligent Mine Program in Scandinavia [3] and the Mining Automation Program [4] in Canada were two main projects attempted in the 1990s and early 2000s. The main technology drivers were seen to be telecommunications, positioning and navigation, integrated software systems, and mobile robotic equipment. The Intelligent Mine Program explored the issues from a rock and process characteristic point-of-view and the Mining Automation Program from an equipment point-of-view.

The optimization of the economics of the process operations is the key driver for the application of advanced control. Many successful control strategy implementations in mineral processing have been reported. The power of model-based control for industrial semi-autogenously grinding circuits was discussed by Herbst and Pate [5]. In the application, they used an expert system and online process models to find the

optimum feed rate. A Kalman filter was used to estimate unmeasured variables such as mill filling and ore hardness, which were required by the expert system. An 8% improvement in feed rate over manual control was achieved with the control system. In the multivariable control application on a two-stage milling circuit at the East Driefontein Gold Mine in South Africa, the average throughput was increased from 73.1 to 79.2 t/h, and the average grain size $<75\ \mu\text{m}$ from 76.5 to 78.5 μm . The standard deviation of the grain size values was reported to decrease from 3 to 0.9 μm [6]. Successful economic results and benefits from 13 years of computer control in flotation have been reported by Miettunen [7].

The economics of the application of intelligent robotics for mining was seen as having substantial benefits. These were discussed by Baiden [8]. This report showed that the fundamental definition of “ore” would be altered by the projected results of cost reduction and mining rate improvements. Further, robotic operation would improve the safety of miners as it would drop exposure levels. Subsequently, the Intelligent Mine Program and Mining Automation Program showed, through field feasibility experimentation, that these projections were realistic. Several projects around the world now are investigating the opportunity for robotic and teleoperated equipment in particular applications.

However, the control of mineral processes is faced with many challenges. At the present time, it is not possible to measure, on a real-time basis, the important physical or chemical properties of the material processes. This is particularly true for the fresh ore feed characteristics (mineral grain size distribution, mineral composition, mineral association, grindability) and the ground material properties (liberation degree, particle composition distribution, particle hydrophobicity). An essential feature of control and optimization strategies is the availability of mathematical models that accurately describe the characteristics of the process. Satisfactory mathematical models are not, however, available for mineral processing unit processes due to the fact that the physics and chemistry of the subprocesses involved are poorly understood. Models for process analysis and optimization for comminuting circuits are usually based on population balance models and the use of breakage and selection functions. Numerous empirical and phenomenological models based on various assumptions for flotation have been proposed in the literature. Among the many flotation models, the classical first-order kinetic model is widely used and can be utilized to optimize the design of flotation circuit and its control strategy. Recently, progress has been made in grinding circuit modeling using the discrete element method (DEM) [9–13] and efforts have been made in the computational fluid dynamics (CFD) modeling of flotation [14].

MINING

Mining, in general, has had little process control capability as mechanization of equipment was the only real opportunity

that existed. For example, the absence of communication systems limited to types of process control that could be applied. In the last two decades, work has been underway to change this. The portable size of computers and the availability of networks to connect them to spawned growth in the application of process control to mining. The basics of main distribution systems such as water and power are now the norm. Networks have further enabled the installation of rock mechanics systems such as microseismic systems. While these systems are important, they do not get to the actual main production technologies because the machine systems for production are mobile.

To describe computer-controlled mining, we must first investigate the very basic process of mining. An ore body has been defined as a mineralization found in the earth, which can be mined at a profit. Many methods exist in the world today to mine an ore body depending on its depth in the ground, size, and rock characteristics.

MINE DESIGN

The first process to gain through the use of computers in mining was the design process. Computers began to be introduced 30 years ago and today computer-aided design (CAD) systems are the norm in all engineering offices. Geologic model in products take diamond drill information and store it in block models, which allows the geologists and mine engineers to use this information to determine grade and quality of the product to be mined. Mining engineers use this information to determine the method to be used in mining and the infrastructure in terms of tunnels and equipment necessary to complete the task. While most of this has been done by hand in the past, new software exists that allows the mine engineer to simulate the sizes and capacities of resources needed to mine the operation.

The mining design software suite of tools is gradually improving each day. The information generated is the key to the control of an effective mining operation.

Open Pit Mining

The most common mining method in the world today is open pit mining. This currently is the most cost-effective way to mine large quantities of low-grade mineralization. Large pits depend on large fleets of mobile equipment that consist of drills, explosives loaders, front end loaders, shovels, trucks, and other secondary equipment. The coordination of these pieces of equipment to accomplish a carefully laid out mine plan requires the operators to accomplish sequenced tasks. While relatively straightforward, this type of operation can get complicated when considering multiple ore bodies, with multiple grades and many pieces of equipment.

The beginnings of automation in open pits have taken the form of using mathematical techniques of linear programming combined with open pit dispatchers sending radio

signals to the operators of the machines based on the calculations done in a rapid computer program. Ideally, this pit dispatcher would sit high above the pit in the control tower similar to that of an airport. This idea will not sound practical in all cases. Environmental conditions such as fog, sand, and snow limited the sight of the pit dispatcher, rendering this form of dispatch inoperable. As time progressed, various schemes for locating equipment were attempted. Some of these schemes included putting beacons in the pit so as equipment drove by dispatchers would know generally where the equipment was located. One of the first attempts at doing this was at the Iron Ore Company of Canada. This system proves successful over the years of running the pit.

The introduction of global positioning system (GPS) for mainstream use by the public was another significant milestone in the process of automating the open pit mining. GPS provided a means to locate equipment within a few meters. The addition of ground station offered the potential for differential GPS and accuracies of a few centimeters. This location ability allows the drilling of accurate holes, knowledge of exactly what explosives were loaded into holes and the location of the mining equipment. This new information technique allowed the elimination of beacons and other infrastructure formerly working in pits. It opened the door to the beginnings of mobile machine automation. One of the earliest applications of GPS systems was with the installation on open pit drills. The results of this work site improvements in whole accuracy and blast performance ultimately leading to better fragmentation of the rock for loading.

GPS systems drove move forward to move from radio systems to networking-type radio systems. Networking systems while a significant move forward in capacity are still well short of the necessary capacity due to the limitations in bandwidth and restrictions imposed by government regulations. The combination of advanced GPS with open pit networks has driven a trend to improve mining and maintenance control of an operation.

Underground Mining

In the 1980s and early 1990s, tremendous research effort went into developing automation systems for underground mining operations. These projects—the Intelligent mine, the Mining Automation Project, and the work at Noranda Technology Center—saw tremendous advances in the systems necessary to telerobotically operate a mine. This work involved the development of high-capacity broadband radio systems, specialized new underground non-GPS positioning systems, electronic solutions for onboard equipment, and new modified mining equipment that behaved as robots. The objectives of working on this technology were twofold. The first main driver was the need to improve worker safety and working conditions. And the second involved improving productivity, quality, and overall economic performance.

The key to computerizing mining operations has been the installation of a foundation communication system. Over

the last 30 years, the introduction of new radio systems to complement the previous hardwired control systems such as telephones has occurred. Investigations for these new radio systems have occurred over that time. And systems from parasitic radio systems to today's high-bandwidth broadband systems have been investigated. It appears that the mining industry in open pit and underground cases is converging on new radio technologies such as 802.11 g.

This new network technology allows the integration of phones, computers, and control systems. Many mines are finding out the advantages of using these new technologies' space in terms of safety, cost, and productivity have been and will be even more significant. These backbone systems are growing in capability allowing for even more significant advantages to be gained. Inco Limited reported the creation of systems for telemining. These two ideas are all based on more significant telecommunications infrastructure. In fact, the systems built allow the formation of the Mining Automation Project (MAP).

Both the Intelligent Mine Program and the Mining Automation Program worked to change this and the concepts behind telemining started to gain momentum in the mid to late 1990s. Telemining (mobile process control for mining) is the application of remote sensing, remote control, and the limited automation of mining equipment and systems to mine mineral ores at a profit. The main technical elements are

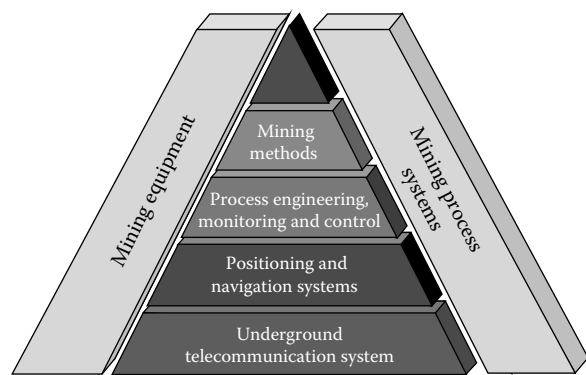
- Advanced underground mobile computer networks
- Positioning and navigation systems
- Mining process monitoring and control software systems
- Mining methods designed specifically for telemining
- Advanced mining equipment

Telemining has the capability to reduce cycle times, improve quality, and increase the efficiency of equipment and personnel, resulting in increased revenue and lower costs.

Mining, in general, has had little process control capability as mechanization of equipment was the only real opportunity that existed. For example, the absence of communication systems limited to types of process control that could be applied. In the last two decades, work has been underway to change this. The portable size of computers and the availability of networks to connect them to spawned growth in the application of process control to mining. The basics of main distribution systems such as water and power are now the norm. Networks have further enabled the installation of rock mechanics systems such as microseismic systems. While these systems are important, they do not get to the actual main production technologies because the machine systems for production are mobile.

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Advanced high-capacity mobile computer networks form the foundation of teleremote mining (Figure 57.1). The mine

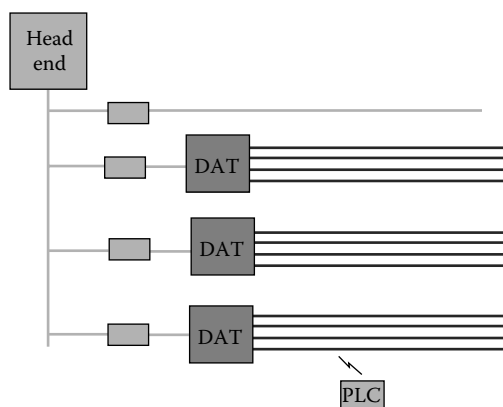
**FIG. 57.1**

Conceptually represents the key technological ingredients. (From Hustrulid, W.A. and Bullock, R.L., *Underground Mining Methods: Engineering Fundamentals and International Case Studies*, Society of Mining Engineers, University Park, PA, 2001.)

may be connected via the telecommunication system, so mines can be run from operation centers (OC) underground or on surface.

Several opportunities exist for communication depending on the environment. Surface mines have trended toward network systems such as 802.11 standards [15] where underground mines have focused on much higher bandwidth systems consisting of a high-capacity backbone linked to 2.4GHz capacity radio cells for communication (Figure 57.2). The high capacity allows the operation of not only data systems but mobile telephones, handheld computers, mobile computers onboard machines, and multiple video channels to run multiple pieces of mining equipment from surface OC [16,17].

To apply mobile robotics to mining, accurate positioning systems are an absolute necessity. Positioning systems that have sufficient accuracy to locate the mobile equipment in real-time at the tolerances necessary for mining have been

**FIG. 57.2**

Example of high-capacity cellular network. (From Hustrulid, W.A. and Bullock, R.L., *Underground Mining Methods: Engineering Fundamentals and International Case Studies*, Society of Mining Engineers, University Park, PA, 2001.)

developed [18,19]. Practical uses of such systems include machine setup, hole location, and remote topographic mapping. Surface systems use GPS for location and several of these systems have been developed. In underground mines, some of the most advanced positioning equipment consists of laser reference positioning, Ring-Laser-Gyro (RLG), and accelerometers. Units are mounted on all types of drilling machines so operators can position the equipment. These types of systems are just beginning to make their presence known over conventional surveying; several manufacturers offer this new product [20]. RLG systems track the location of mobile machinery in the mine. Accurate positioning systems mounted on mobile equipment will enable the application of advanced manufacturing robotics to mining. Usually, in advanced manufacturing, robotic equipment is fixed to the floor allowing very accurate surveying and positioning of the equipment. The positioning systems being used for mining equipment allow accurate positioning of surface equipment using GPS and inference techniques allow low-accuracy positioning of mobile underground equipment.

Mine planning, simulation, and process control systems (PCS) are growing using the foundations of telecommunications, positioning, and navigation. Linking geology and engineering directly to operations is important to the successful application of these systems. Several systems such as Datamine, Gemcom, Mine 24D to name a few, are in use around the world today. Further, PCS for the day-to-day operation of pumping, dewatering, and power distribution are the norm. New systems for ventilation control are starting to emerge as the cost of the overall system infrastructure is reduced.

MILLING AND PROCESSING

Milling and processing operations are typically controlled using distributed control systems (DCS). These operations are linked by communication systems to sensors and actuators in the plants. In some cases, the mine control systems provide information to the DCS to support the ongoing processing ore.

Today's DCS systems have evolved from proprietary systems to open source systems that follow standards that allow many different types of sensors and actuators to connect. This evolution has opened the door to many new types of control. For example, artificial intelligent (AI) have seen a rapid deployment of milling and processing systems.

The overall objective of a grinding and flotation unit is to prepare a concentrate, maximizing as the net revenue of the plant. In practice, however, the links between the grinding and flotation circuits tuning and the economic objective are not obvious, and the objectives are always broken down into particle size reduction, mineral liberation, and mineral separation objectives. In the following, grinding and flotation areas are briefly discussed as application areas where automation has played an important role in mineral processing.

These application areas serve as examples of current developments in the field of automation in mineral processing.

Grinding

Grinding ore to the optimum size for mineral extraction by flotation or leaching is an essential but high-energy-intensive part of most mineral processing operations. The benefits from improved grinding control are substantial, primarily in the areas of improved milling efficiency, more stable operation, higher throughput, and improved downstream processing. Grinding an ore finer than is necessary leads to increased energy costs, reduced throughput, increased mill liner consumption, and increased consumption of grinding media and reagents. Insufficient ore grinding, on the other hand, reduces the recovery rate of the valuable mineral.

Instrumentation

For grinding instrumentation, both basic measurement and advanced indirect instruments are available. The most common measurements are mass flow rate on a conveyor belt, volume flow rate, pipeline pressure, pulp density, sump level, mill motor power consumption, and mill rotation speed. Online particle size measurement is also a part of the well-instrumented grinding circuit. Indirect instruments are mostly used in mill or hydrocyclone operation monitoring. These measurements are based, for example, on acoustic measurements, vision-based monitoring, mill liner sensors, and mill power frequency analysis. More information on hydrocyclones can be found in Chapter 56.

Mass flow rate measurement on a conveyor belt is mainly performed by nuclear weight gauges. In pipeline flow measurements, magnetic instruments are the most typical. Pulp densities can be measured by a nuclear density meter, soft sensors, or alternatively, by certain particle size analyzers.

Online particle size analysis can be performed using several techniques. The three most typical online particle size analysis methods in mineral processes are mechanical-, ultrasonic-, and laser diffraction-based devices. Outotec's PSI-200 has been one of the most popular mechanical devices since the 1970s. The measurement is based on a reciprocating caliper with high-precision position measurement. The measurement technique limits accurate size measurement to the coarser end of the distribution. The ultrasonic-based measurements were also developed in the 1970s, for example, the Svedala Multipoint PSM-400. However, the method requires frequent calibration and is susceptible to airbubbles. The laser diffraction method represents the latest technology in online particle size analysis. The PSI-500 particle size analyzer, manufactured by Outotec, uses laser diffraction-based measurement, with automatic sample preparation. The system enables the development of new advanced control employing the full scale of the particle size distribution [21].

Some vision-based measurements have recently been developed. Mintek has a product CYCAM for hydrocyclone

underflow monitoring. The equipment measures the angle of the discharge and therefore the conditions: for example, roping can be detected. For particle size, on-belt monitoring of the grinding and crushing circuit Metso has a product called VisioRock.

Various methods are used for mill charge measurement. These include acoustic measurements [10], mill liner sensors, and mill power frequency analysis [22–24]. The methods are mostly applied to specific processes, and there have been no significant commercial product breakthroughs.

To summarize, an example of a grinding circuit with typical instrumentation is given in [Figure 57.3](#).

Grinding Control

Control of the wet mineral grinding circuits might have different objectives depending on the application. The most common control objectives are

- The particle size distribution of the circuit product is to be maintained constant at constant feed rate.
- The particle size distribution of the circuit product is to be maintained constant at maximum feed rate.
- Both the particle size distribution and solid contents circuit product are to remain constant.

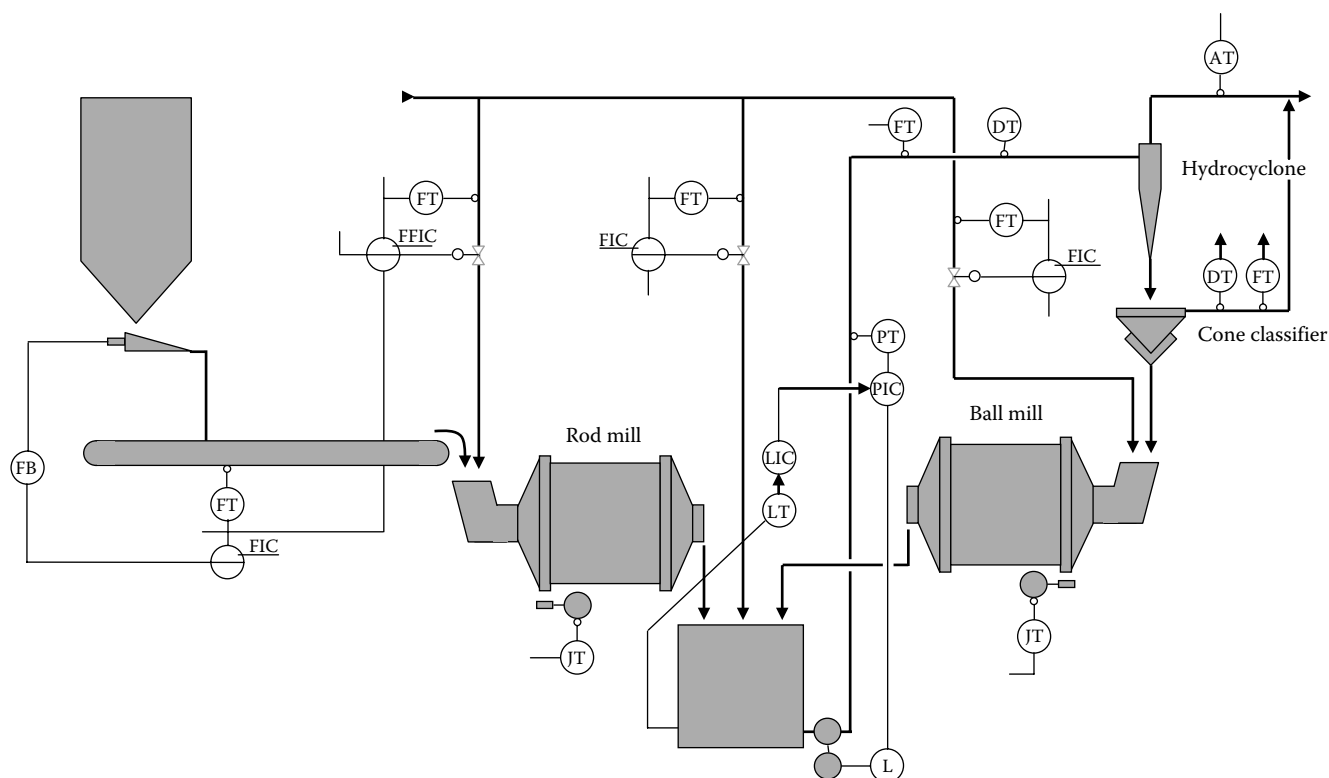
The control strategy for the grinding circuit is based on a hierarchical structure. Basic controls mainly consist of traditional PID controllers and ratio controllers. The mill water typically has a ratio control with the ore feed. In many cases, sump levels are controlled by changing the pump speed. Through the hydrocyclone feed pressure control. The cyclone feed density is stabilized by manipulating an additional water feed rate to the sump. Particle size measurement is also currently applied in grinding circuit control. The product particle size measurement can, for example, be used to manipulate the ore feed rate to the primary mill. In addition, higher level optimization methods are typically applied to maximize the throughput with desired constraints.

Flotation

In flotation, the aim of the control strategy is adjustment of the operating conditions as a function of the raw ore properties and feed rate, metal market prices, energy, and reagent costs [26]. Usually, these objectives require a certain amount of trade-off between the concentrate grade and tonnage, the impurity contents, and the operating costs.

Instrumentation

In flotation, instrumentation is available for measuring flow rates, density, cell levels, airflow rates, reagent feed rates, pH, Eh, and conductivity. Slurry flow measurement is mainly performed by a magnetic flow meter and density by a nuclear density meter. The most typical instruments used for

**FIG. 57.3**

Typical flowsheet of a grinding circuit. AT, Analysis (particle size); FT, density; FT, flow. (From Jämsä-Jounela, S.-L., *Modern Approaches to Control of Mineral Processing*, Acta Polytechnica Scandinavica, Mathematic and Computer Science Series No. 57, Helsinki, Finland, pp. 57–61, 1990.)

measuring the slurry level in a cell are a float with a target plate and ultrasonic level transmitter, a float with angle arms and capacitive angle transmitter, and reflex radar. The instrument for measuring flotation airflow rate contains a thermal gas mass flow sensor or a differential pressure transmitter with a venture tube, pitot tube, or annubar element. A wide range of different instrumentation solutions for reagent dosing exist. The best choice is to use inductive flow meters and control valves. Electrochemical measurements give important information about the surface chemistry of valuable and gangue minerals in the process. pH is the most commonly measured electrochemical potential, and sometimes pH measurement can be replaced by conductivity measurement, which gives approximately the same information as pH measurement. Recently, other electrochemical potential measurements have also been under study. The use of minerals as working electrodes makes it possible to detect the oxidation state of different minerals and to control their floatability. Stability of the electrodes has been, however, a problem in online use, but some good results have been reported.

X-ray fluorescence is the universal method for online solid composition measurement in flotation. Equipment vendors now offer, however, more efficient, compact, flexible, and reliable devices than were available in the 1970s.

To summarize, an example of a flotation circuit with typical basic instrumentation is given in Figure 57.4. Conductivity

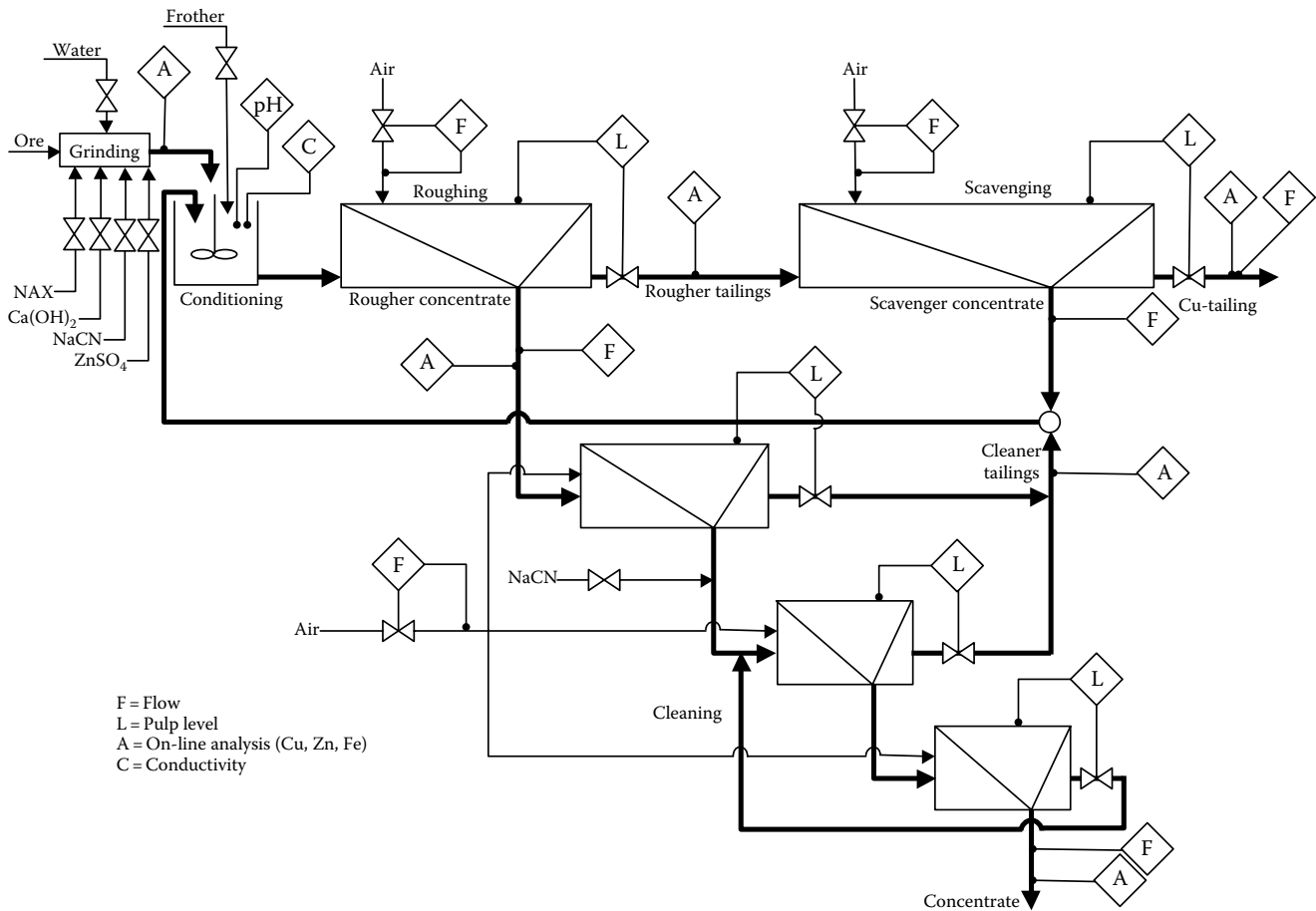
and pH are measured in the conditioner. On-stream analyses are taken from the feed, tailings, and concentrate and also from several flows between the flotation sections. Flow rates, levels, and airflow rates are measured at several points. Most of the reagents are added in the grinding circuit, except the frother that is added in the conditioner, and additional sodium cyanide in the cleaner.

Recent developments in instrumentation have provided new instruments, such as image analysis-based devices for froth characteristics measurement. Three different image analysis products have been reported to be available commercially: FrothMaster from Outotech, JK Froth Cam from JK Tech, and VisioFroth from Metso Minerals. Research has been carried out on developing image processing algorithms and on analyzing the correlations between image analysis and process variables, more recently also on flotation control based on image analysis.

A comprehensive description of the flotation plant instrumentation has been reported by Laurila et al. [27].

Flotation Control

Flotation control designed according to the classical control hierarchy of base level controls, stabilizing control, and optimizing control has been widely accepted as a mature technology since 1970. Basic controls consist of traditional PI

**FIG. 57.4**

Typical flowsheet of a flotation process (Cu circuit of Pyhäsalmi concentrator). (From Laurila, H. et al., *Mineral Processing Plant Design, Practice and Control*, Littleton, CO, 2002.)

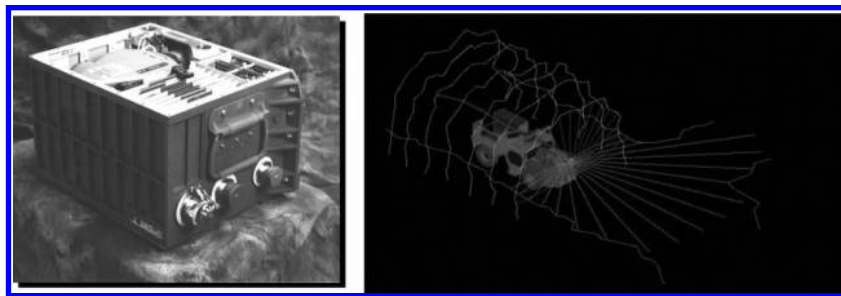
controllers for cell levels, and airflow rates. A feedforward ratio controller is used for reagent flow rates. For cell levels in series, a combination of feedforward and multivariable control strategy has been also widely applied in industrial use [28].

Developing flotation control strategies is still an active research topic since the benefits to be gained in terms of improved metallurgical performance are substantial. However, flotation control is becoming more and more difficult due to the emergence of low grade and complex ores. Machine vision technology provides a novel solution to several of the problems encountered in conventional flotation control systems, like the effects of various disturbances appearing in the froth phase. Structural characteristics such as bubble diameter and froth mobility give valuable information for following the trend in metal grade and recovery.

In the FrothMaster-based control in the rougher flotation at Cadia Hills Gold Mine in New South Wales, Australia, three FrothMaster units measure froth speed, bubble size, and froth stability. The control strategy contains stabilizing and optimizing options. Stabilizing control strategy is logic based and manipulates the level, frother addition rate,

and aeration rate to control the froth speed. Optimizing control of the grade changes the set point values of the froth speed [29]. Many industrial implementations of the JK Froth Cam system have been reported as well. The control system consists of PID controllers and/or an expert system. Measurements of bubble size, froth structure, and froth velocity are taken and reagent dosages, cell level, and aeration rates are used as manipulated variables [30]. VisioFroth is one module in the Metso Minerals CISA optimizing control system, by which froth velocity, bubble size distribution, and froth color can be measured. The largest VisioFroth installations are at Freeport, Indonesia, with 172 cameras and Minera escondida Phase IV, Chile, with 102 cameras. A combination of onstream analysis and image analysis technology seems to be the most efficient way to control flotation today. Better concentrate grade consistency, and thus improved plant recovery, have been reported using this combination [31].

Flotation, being a time variant and nonlinear process that usually also undergoes large unknown disturbances is, however, difficult to manage optimally by classical linear control theory applications. Operator support systems are

**FIG. 57.5**

RLG and test-bed surveying unit. (From Hustrulid, W.A. and Bullock, R.L. Underground Mining Methods: Engineering Fundamentals and International Case Studies, Society of Mining Engineers, University Park, PA, 2001.)

needed to overcome these problematic situations. The latest applications of the operator support systems are concentrating on solving the issue of feed-type classification. At many mines, changes in the mineralogy of the concentrator feed cause problems in process control. After a change in the feed type, a new process control slightly has to be found. This is usually done by experimentation because the new type is often unknown. These experiments take time and the resulting treatment method might not be optimal. The monitoring system developed by Jämsä-Jounela et al. [32] uses SOM for online identification of the feed ore type, and a knowledge database that contains information about how to handle a specific ore type. A self-learning algorithm scans historical data in order to suggest the best control strategy. The key for successful implementations is the right selection of variables for the ore-type determination.

FUTURE TRENDS

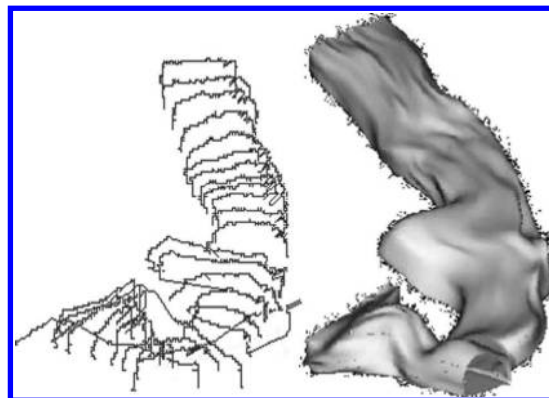
Emerging trends in mining will likely take the form of moving toward advanced manufacturing techniques. Telecommunications systems in surface and underground have opened the door to a completely new thinking in mining. The three biggest trends will be advances in positioning system, telerobotic control of machinery, and the new techniques these systems will introduce.

Work continues in the research field in building the equivalent to GPS for underground. This technology development was recently reported at Massmin 2008 in Lulea, Sweden [33]. This new development combined with gyro technology will alter current practices in ways not yet comprehended. If this technology could be combined with an RLG and laser scanners mounted on a mobile machine such as shown in Figure 57.5 Machines can have knowledge of positioning in real time on board the machine. Tasks such as mapping, drill setup, and machine guidance systems will become simple to implement. Figure 57.5 shows a RLG and a concept of a machine for surveying. Figure 57.6 shows the actual mapping data collected by this surveying machine. At present, this unit is capable of surveying a 1 km drift (tunnel) in a few hours as opposed to several days using current work

practices. The addition of an equivalent to GPS for underground will improve this technology and many more.

Another important trend is enabled by advances being made in communications capacity. The operation of telere-mote equipment is possible for all processes and equipment. An operator station, as shown in Figure 57.7, is connected to the machine via the telecommunications system. This allows the operator to run several machines simultaneously and together with positioning and navigation systems will allow the operator to instantaneously move from machine to machine across multiple mine environments. Several mines around the world are attempting this technology in operation. The list includes Inco, LKAB, Rio Tinto, and Codelco.

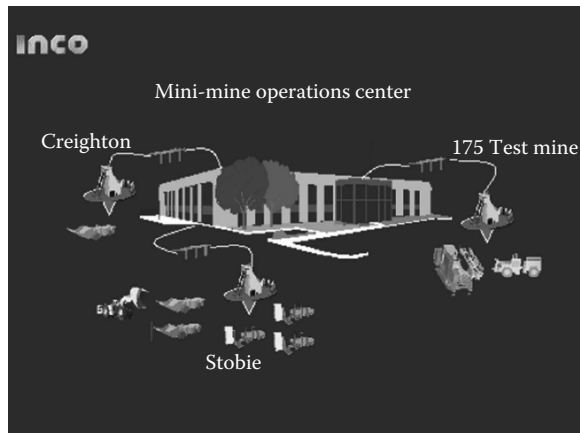
As the technology becomes more widespread, it will allow mining companies to consider the installation of mine operation centers (MOCs) such as the one shown in Figure 57.8. Prototypes have been designed and installed around the world. The figure shows a MOC, which connects Stobie Mine, Creighton Mine, and the Research Mine at Inco. As seen in this picture, are all connected to the MOC. Three Tamrock Datasolo Drills and five load haul dump (LHD) of various types are working or have worked from the MOC since its inception.

**FIG. 57.6**

Software generated drift from test-bed machine data. (From Hustrulid, W.A. and Bullock, R.L. Underground Mining Methods: Engineering Fundamentals and International Case Studies, Society of Mining Engineers, University Park, PA, 2001.)

**FIG. 57.7**

Teleremote operation chair. (From Hustrulid, W.A. and Bullock, R.L., Underground Mining Methods: Engineering Fundamentals and International Case Studies, Society of Mining Engineers, University Park, PA, 2001.)

**FIG. 57.8**

Mines operation center.

Benefits

Significant benefits of this teleremote style of operation are in safety, productivity, and value-added time. Operators spend less time underground thus reducing exposure to underground hazards, and productivity is improved from

the current one person per machine to one person per three machines. Initial tests indicate that 23 continuous operations in a 24 h period is possible, which is significantly better than the current 15 h. Clearly, capital requirements in the latter situation are reduced.

The effectiveness of teleremote mining may be analyzed in the short term using computer-based simulation systems, which are powerful quantification and visualization tools of technology and operations. The following example shows the impact of the teleoperated mining technology to throughput, mine life, better resource utilization, and increased value generation for the organization.

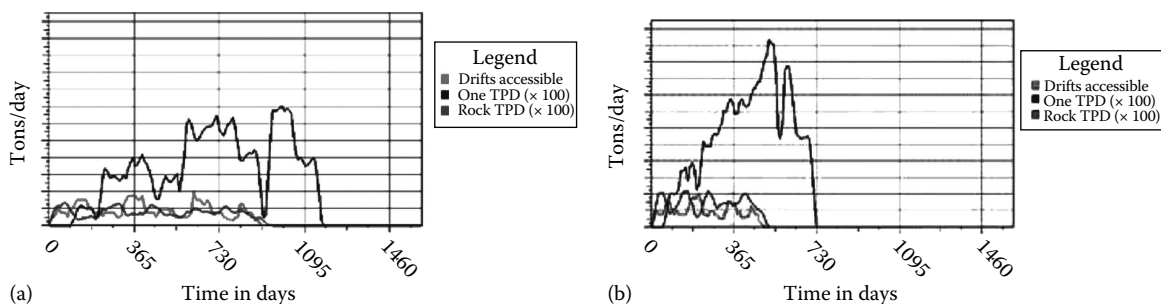
Evaluation of Teleoperated Mining

A simulation model was used to evaluate the impact of teleremote operations on mine life and provide outputs required to make planning decisions. Teleremote operations have been shown in an operating mine to be capable of 7–7.5 h of operation per 8 h shift as compared to 5 h in a conventional mine. Other significant differences between conventional and telerobotic mining has increased flexibility and safety.

The comparative graphs in Figure 57.9 show significant potential results from the application of robotics and automation. Mine life is reduced by 38% using teleremote mining versus conventional mining because of the higher mining rate from improved throughput and face utilization. Moreover, utilization of LHD equipment is increased by 80% in teleremote mining compared to conventional settings. With a total of two LHDs, high rates of production were achieved.

Modern automation systems in plants, which have to process ever more complex ore, are faced with the challenge of incorporating the increasing capabilities of modern technology in order to be able to succeed in a very competitive and global market, in which product variety and complexity, as well as quality requirements are increasing and environmental issues are playing ever more important key roles.

Process automation systems provide important plant operational information such as metallurgical accounting, mass balances, production and process management, energy management, and optimization. Mines and processing

**FIG. 57.9**

Conventional and teleremote mine life comparisons. (a) Conventional Blasthole Mining; (b) Teleoperated Blasthole Mining. (From Hustrulid, W.A. and Bullock, R.L., Underground Mining Methods: Engineering Fundamentals and International Case Studies, Society of Mining Engineers, University Park, PA, 2001.)

plants need integrated PCS that can improve plant-wide efficiency and productivity. Advances in information technology have provided the capabilities for sharing information across the globe and, as such, process automation and control have become more directly responsible for assisting in the financial decision-making of companies. The future aim of the system approach is to cover the complete value-added chain from the mine to the end product, and to utilize the latest hardware and software technology advances in their systems.

The optimization methods for grinding control are expected to be developed due to better particle distribution measurement systems, advanced mill condition measurements (e.g., frequency analysis), and the use of efficient grinding simulations based, for instance, on the DEM. Flotation is facing a new era in terms of process control and automation. Flotation cells have increased in size dramatically over the past years; flotation circuit design of multiple recycle streams will be replaced by simpler circuits, subsequently leading to a decreasing number of instruments with higher demands on reliability and accuracy. This will set new challenges for the control system design and implementation of these new plants. Process data-driven monitoring methods, model predictive control (MPC) and fault tolerant control (FTC) will be among the most favorable methods to be applied together with the recently developed new measurement instruments.

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